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Sustainability of the future; rethinking the fundamentals of energy research☆

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Abstract

The demand for energy services (which must not be mistaken for the demand for energy itself) is proportional to the world's wealth, which, as monitored for the past 1000 years, still increases exponentially. Current efforts in controlling the resulting rise in energy demand mainly focus on efficiency improvement and sustainable conversion technologies. This paper demonstrates that these technological efforts most likely cannot provide long-term alternatives. At best, they can buy some time during which long-term sustainable solutions can be developed.

There are two effective long-term solutions to energy related problems. The first would be the discovery of a sustainable energy source with an unlimited potential that can cater for an exponentially growing demand. The second is to limit economic growth, which would also stop the corresponding demand for energy services. In this case, sustainable energy sources with limited potential or resources can provide sufficient energy.

As a first crucial step, research efforts should focus on quantifying the demand for energy services and estimate how much energy man, at his thermodynamical limits, will still need. This knowledge can further on establish the timeframe for implementing an effective long-term solution.

☆ Energy research needs to be innovated for long-term vision. The current focus on efficiency improvement and sustainable energy sources holds no long-term solution for satisfying exponentially rising energy needs.

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1. Introduction

Professor Van Cauteren[1] once postulated that "*everything is coagulated energy*". This claim can be vulgarised as "*everything is energy*". Since "*everything*" appears to expand rapidly, Van Cauteren's postulate implies that the need for energy will expand accordingly.

The driving forces behind the increasing need for energy services are a growing population and the rising standard of living of individuals, which can be measured in the GDP per capita. Fig. 1A demonstrates that over a very long time scale, both the population and the GDP per capita appear to rise faster than exponentially (the curves are plotted relative to the levels in 1900) (see [1,2]). For the last century, Fig. 1B shows that both super-exponential slopes appear to have edged toward plain exponential curves. If the need for energy services is deemed to be directly dependent on both factors, one can conclude that the need for energy services will at least also increase exponentially. Gates [3] shows that, from the mid-1800s to the mid-1900s, the need for energy has risen exponentially.

Because of efficiency improvements and reduced energy intensities (a standard for energy use per unit of productivity) (see [4]), energy use is expected to rise more moderately than the demand for energy services.

As a result, we can sketch the evolution of energy use and the demand for energy services in Fig. 2. Note that both energy and energy services are expres-

[1] Richard Van Cauteren (1903–1987) was a professor in thermodynamics at the University of Leuven (K.U. Leuven), Belgium.

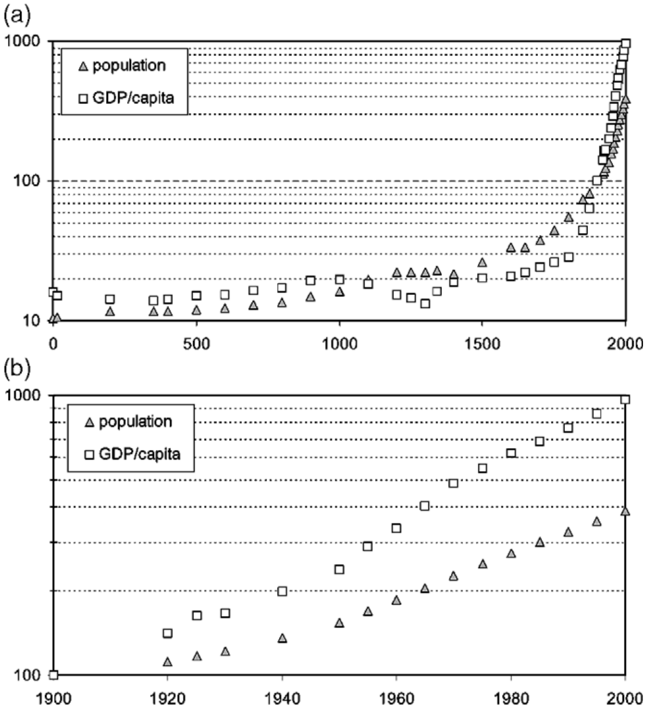


Fig. 1. Evolution of the world's population and the average GDP per capita.

sed in energetic units. For energy services, this is not straightforward (as will be shown later on). Expressing these energy services in energetic units is a first challenge for future research. The demand for energy services rises exponentially in line with demographic and economic trends. Even if population growth stabilises (which is likely in the near to distant future), demand for energy services will still rise exponentially according to economic growth. Energy demand also grows exponentially, albeit at a slower pace than the demand for energy services, because of efficiency improvement. However, although short-term declines of energy use may occur (due to drastic and revolutionary efficiency improvements), energy use will inexorably rise since the demand for energy services represents the unreachable limit for energy demand. To do better than the demand for energy services would be a violation of the first law of thermodynamics.

The questions raised in this paper are whether we can cope with this rising energy demand and how to make the long-term future energetically sustainable. Until now, man has tried to tackle these problems technologically. Fig. 2 shows that this technological approach will sooner or later reach its limits ... Unfortunately, the author cannot provide full answers to these questions (yet), but merely proposes that new research domains need to be opened.

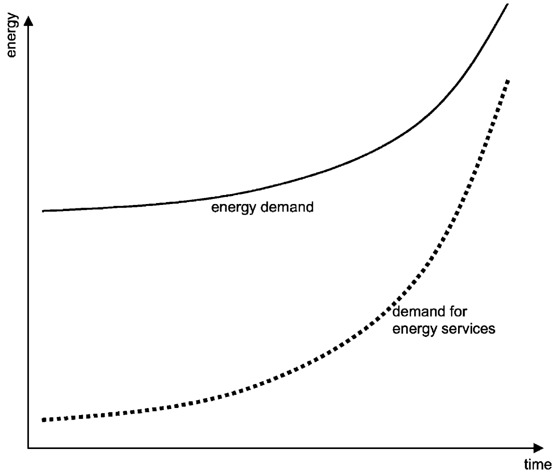


Fig. 2. Evolution of the demand for energy and energy services.

The paper might seem controversial and may even shock some readers because it not only criticises our current way of using energy or doing research but even tackles the ultimate taboo of the need for economic growth. It is also important to interpret widely the concept of time to fully grasp the impact of this paper. The timeframe considered here spans hundreds of years, where most "problem solvers" focus on electoral periods of less than 10 years.

2. Energy versus energy services

Mankind has no need for energy carriers such as coal, gas, oil, wood or electricity. We need energy *services*. Energy itself is a fairly straightforward concept which is technologically definable and can easily be quantified (either in TJ, GWh, Mtoe, Gcal or MBtu). Energy services, on the other hand, are abstract, independent of technology and are difficult to quantify. This is demonstrated in few examples.

1. I drive my car to the opera, enjoy Puccini's finest, and return home in my car. For this purpose, I have used an amount of fuel: *energy*. The *energy service* in this case might be described as the distance I need to travel back and forth to the opera. One could go even further and state that the basic energy service is for me to enjoy Puccini's finest in real time. Currently, science is working hard to improve the efficiency of physical transport between my home and the opera. Future generations might attempt to virtually transport me to the opera or to bring a holographic projection of the opera to my home.
2. I like to feel warm and cosy in my house. To do so, I burn gas, *energy*, in a central heating system that feeds my radiators. For heating purposes, the energy service is often described as the room temperature desired. In my case, this is

19–20 °C. More basically, it is enough to heat the immediate neighbourhood of my skin. The final step is to state that I want to feel comfortable, warm and cosy... Present-day scientists try to improve furnace efficiency or wall insulation. Future colleagues might develop smarter portable heat sources or invent insulating body layers or sprays.

The examples clearly demonstrate that, whereas the concept *energy* is straightforward, *energy services* are difficult to define objectively. They also indicate that *energy* is largely technology linked and *energy services* are not; they are abstract notions of desires of individuals. Basically, when all technological influences are eliminated, only the concept of *comfort* remains. Therefore, it is fair to assume *energy services* to be proportional to *comfort*, which is measured by GDP per capita. Hence, the demand for energy services is outlined in Fig. 2 along with the energy consumed to fulfil these services. The demand for energy services, in line with the world's GDP, rises exponentially.

In a hypothetical world where all applications operate without losses (man at his thermodynamical limits), the two curves of energy and energy services coincide. The energy curve can never cross the curve of energy services without violating the laws of thermodynamics.

3. A technological solution?

Energy related issues (such as the depletion of energy resources or the greenhouse effect) are currently approached with technological "*plumbing*". There are two broad tendencies: efficiency improvement of demand-side applications and the development or exploration of more sustainable energy conversion technologies.

3.1. Efficiency improvement

The reduction of energy use in order to supply a given energy service can be achieved by developing appliances with a better efficiency. Von Weizäcker et al. [4] claim that a spectacular reduction in total primary energy use of at least 50% is possible, even when wealth doubles (which results in their famous *Factor Four*). The effect of this improvement is that the curve of energy consumption further approaches the curve of demand for energy services. The effect of *Factor Four* is demonstrated in Fig. 3 (abstraction is made of renewable energy sources which are discussed separately in the next section). Spectacular as the Factor Four may be, in the long term, energy use still rises exponentially since the energy–service curve has not changed and cannot be crossed. Although the long-term doomsday scenario remains, Factor Four has two main merits: it demonstrates that, currently, energy is not efficiently utilised and it postpones the dramatic rise in energy use. This last merit allows the luxury of more time to find an adequate long-term solution.

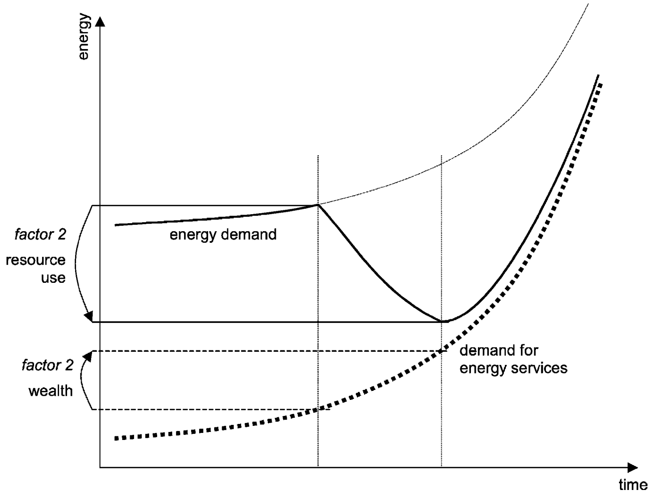


Fig. 3. Energy demand and energy services in the Factor Four scenario.

3.2. Sustainable conversion technologies

Another proposed solution to energy related problems consists of sustainable conversion technologies. Some advocate renewable technologies (from hydro power to a photovoltaic hydrogen economy); others believe that an expansion of the share of nuclear energy will solve all problems.

Although the debate on the precise potential of renewable energy sources is far from being settled, all agree that it is finite. Since the demand for energy services rises exponentially, at some point in time, these finite renewable sources will be insufficient to satisfy demand. This is demonstrated in Fig. 4. Although the renewable share appears large, the share of *conventional* conversion technologies still increases exponentially in the long run.

A similar pattern can be found for nuclear energy. Here, the limited potential relates to the uranium resources. This implies that, for nuclear fission, the share is not constant in time, but will decline at some point.

Again, both renewable and nuclear energy can assist in prolonging the use of other energy carriers, which provides more time to investigate permanent solutions.

3.3. Interpretation and conclusion

It might be typical for a tender green technological civilisation (mankind has existed for millions of years and has only had access to technology for the last few centuries) to defiantly assume that every problem has a technological solution. In the case of energy related problems, there are two main schools of thought: the demand- and the supply-side adepts. The demand-side group focuses on efficiently improvement of final applications. On the supply side, the development, explo-

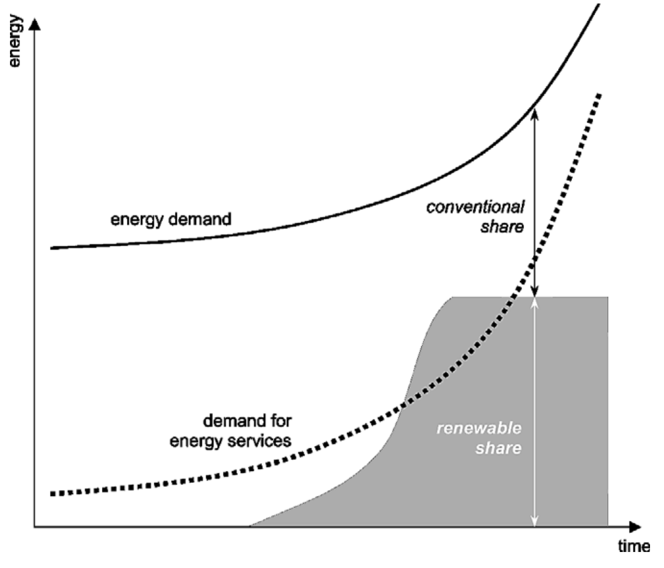


Fig. 4. Energy demand and energy services in the renewable energy scenario.

ration and further application of renewable energy sources or nuclear power are pursued.

Although both factions argue unceasingly (and are even internally divided), it is demonstrated that neither one provides a long-term sustainable solution compatible with the exponentially growing demand for energy services. Their only merit is that they prolong the use of conventional energy carriers (possibly by several centuries) and provide time to design a truly sustainable path.

4. Long-term sustainable solutions

When carefully interpreting the implications of Fig. 2, there are only two long-term sustainable alternatives. One is the development or exploration of sustainable technologies with exponentially growing resources. The second is the stabilisation of demand for energy services.

4.1. Unlimited sustainable resources

We already established that sustainable energy sources, with limited resources or with finite potential, will sooner or later (hundreds of years) fail to satisfy an exponentially growing demand for energy services. Therefore, in theory and over an unspecified period of time, an *infinite* energy source is needed. This source is yet to be discovered.

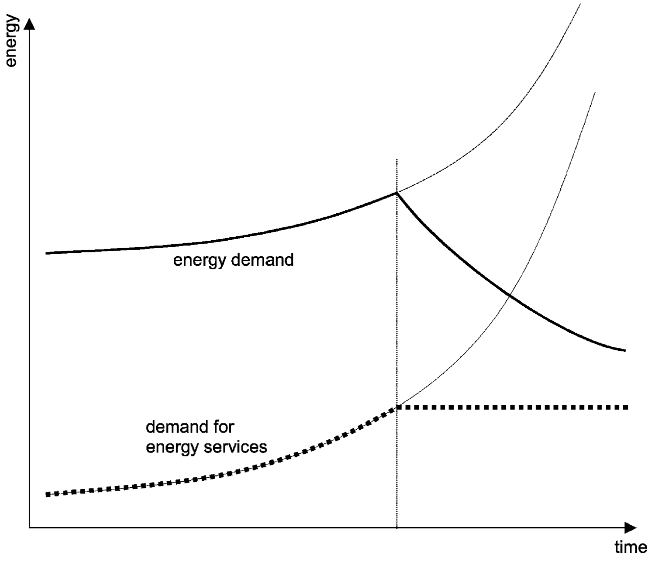


Fig. 5. Energy demand and energy services in a stagnating economy.

4.2. Stabilisation of demand for energy services

Another manner in which limited resources and sustainable sources with a finite potential can, in the very long term, cover all energy needs is for energy demand to be capped. Since energy demand is determined on the basis of the demand for energy services, this generic demand for energy services needs to stabilise. This is demonstrated in Fig. 5.

We already established a link between the demand for energy services, comfort and the world's GDP. Therefore, in order to stabilise demand for energy services, the growth in GDP needs to cease. In the assumption that the world's population will not rise infinitely (because of limited space), this means that the GDP per capita, which can be expressed as the standard of living per person, needs to stabilise. This is contradictory to the current appetite for a growing economy. In human evolution, stagnation is the ultimate taboo. It is nevertheless a valid question to ask *why* the world economy needs to grow (providing developing countries are left the opportunity to develop to acceptable standards). Why is stagnation unacceptable? Why can society not simply be content with the present without demanding *more* than past generations? Thus, the discussion crosses the border from a purely energetic to a broader ideological level.

5. Conclusions

Present-day research attempts to find technological solutions for energy related problems. Since none of these solutions manages to adequately provide exponen-

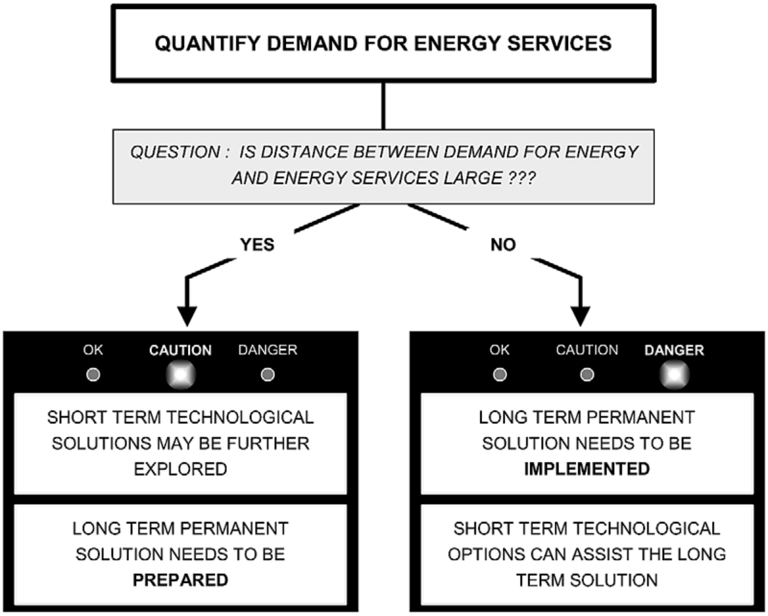


Fig. 6. Need for new energy research structure.

tially growing energy services, they can only be used as temporary and transitional options.

For long-term sustainable energy provision, either an energy carrier with exponentially growing potential is needed or economic stagnation needs to be implemented.

6. Author's interpretation

Research is currently focused on solving short-term problems by modifying or fine-tuning existing technologies. As this strategy has worked until now, mankind cherishes the artificial optimism that every potential problem will effectively be solved (an optimism that is further amplified by the statistics of Lomborg [5]). This train of thought is flawed. It is not a given that because most past strategies have worked every future one will automatically succeed. One cannot extrapolate past known events to an uncertain and unpredictable future.

Another problem is the commercialisation of research. Inadequacy of government grants necessitates financing from industry, where short-term results are demanded. Tangible results have become more important than fundamental thinking patterns. Abstract ideas and vision are dismissed if they do not provide immediate practical applications.

This is alarming because the short-term “patching up” of energy related problems is only acceptable as a temporary measure and should be subordinate to the quest for a long-term solution.

7. Need for further research

Energy research needs to be fundamentally restructured and rethought. The required energy research structure is schematically shown in Fig. 6. As a first important step, the need for energy services has to be quantified. This step is necessary to establish *how much time* there is left to search for permanent solutions.

1. CAUTION! If the demand for energy services is much lower than the current energy demand, there is still some time to explore short-term technological solutions to further converge towards the energy–service curve, keeping in mind that a permanent solution will one day to be achieved.
2. DANGER! When energy demand gets close to the demand for energy services, a permanent solution needs to be ready and implemented. Short-term technological solution can assist this implementation, but are not the main goal.

In any case, the first crucial step is the identification of the need for energy services.

Acknowledgements

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